

## **Constellation-X**

### **Top Level Requirements**

**Version of 07/20/00**

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## 1. SCOPE

The purpose of this document is to provide a self-consistent set of top level requirements for Constellation-X in a form that can be used to develop and refine a reference mission, and that provides traceability to the fundamental science requirements for the mission.

## 2. INTRODUCTION

The scientific objectives of the Constellation-X mission are briefly summarized in Section 2.1. More complete descriptions of the mission's scientific objectives can be found in the original mission proposals by GSFC (PI. Nick White) and SAO (P.I. H. Tananbaum) and in REF the SCIENCE BOOK that can be found at the Constellation-X website (<http://constellation.gsfc.nasa.gov/>). The requirements that must be met by the mission and spacecraft systems to achieve these objectives are defined in Section 3. The requirements defined in this document, unless otherwise noted, are applicable to the full constellation of mission satellites, under normal mission operations.

Some of the requirements require additional explanation for clarity. In these cases, the explanations are provided in italics following the statement of the requirement.

### 2.1 Constellation-X Science Objectives

The purpose of the Constellation-X mission is to study the structure and dynamics of cosmic X-ray sources by obtaining high resolution, high signal-to-noise X-ray spectra. Sources of interest include matter under extreme gravity (supermassive black holes and stellar endpoints), galaxies, clusters of galaxies and the intergalactic medium, stellar coronae and the interstellar medium (ISM), and Solar System objects. These objects emit strongly in the X-ray energy regime, and vary in intensity on a broad range of timescales. The Constellation-X mission shall be designed to study these spectra and their variations on timescales from microseconds to years.

The fundamental Science Objectives are to:

- I. Measure the X-ray spectra of the faintest sources in the ROSAT Deep Surveys ( $2 \times 10^{-15}$  ergs  $\text{cm}^{-2} \text{ s}^{-1}$  in the band 0.2 to 2 keV) and the Chandra deep fields (over the band 2.0 to 10 keV) in less than  $10^5$  seconds.
- II. Test General Relativity in the strong gravity limit by mapping the inner emission regions of black holes.

- III. Search for the “dark matter” or “missing baryons” from observations of the intergalactic medium (IGM)
- IV. Study the interchange of matter and energy between stars and the ISM, and the enrichment of the IGM and ICM and the evolution of clusters of galaxies.

[Note: the above list is a severely shortened version of the mission’s science objectives and is intended to be representative rather than comprehensive.]

### 3. MISSION REQUIREMENTS

The mission requirements delineated below are intended to be consistent with achieving the science objectives as summarized in Section 1.1. These requirements, unless otherwise stated, apply to the entire mission from the beginning of normal mission operations through end of life. Normal mission operations commence when all elements are in place and normal science observations have begun.

#### 3.1 Band Pass

The instantaneous mission X-ray bandpass shall be from 0.25 keV to 40 keV. This bandpass may be implemented by using several instruments with narrower bandpasses.

The goal for the instantaneous mission bandpass is <0.20 to >60 keV.

*A broad bandpass is required to address Science Objectives I – IV. Many cosmic sources exhibit spectral features over a broad range of energies. These include Active Galactic Nuclei (AGN), in which Compton reflection off surrounding cold material produces a continuum spectrum at energies > 10 keV; stellar flares, in which a hard, non-thermal impulsive continuum above 10 keV can accompany the thermal emission produced during coronal heating events below 2 keV; and Supernova Remnants (SNRs), in which the synchrotron radiation generated by cosmic ray electrons accelerated at the shock front can produce a high energy tail in addition to the thermal component.*

#### 3.2 Spectral Resolution

The required mission spectral resolving powers across the mission bandpass are defined in the table below:

**Table I**  
**Minimum Resolving Power**

Energy (keV)	Minimum Mission Spectral Resolving Power (E/DE)	Goals
0.25 to 10.0	300	600

6.0 – 8.5 (TBR)	3000	TBD
8.5 – 10	3000	TBD
10 – 40	10	TBD

*The minimum spectral resolutions are required to achieve Science Objectives II and IV. The minimum spectral resolution anywhere over the line-rich 0.25 – 10 keV bandpass is set by the conditions that 1) that there be sufficient resolution to separate the important density-sensitive He-like triplets (resonance, forbidden and intercombination lines) arising from the O, N, Mg, Si and S ions and 2) that the majority of the individual spectral lines in this bandpass be resolved. The spectral resolving power in the 6.0 – 8.5 keV bandpass must be high enough to 1) distinguish the lithium-like satellite lines from the overlapping helium-like transitions and 2) achieve a velocity resolution of at least  $20 \text{ km s}^{-1}$  in the Fe lines.*

*[There was a comment by N. White in the 4/11/00 meeting that the velocity resolution needed to be higher. Azita also noted that the Ni line above 8 keV requires high resolution to separate it from underlying iron emission. ]*

### 3.3 Spectral Accuracy

From 0.25 to 10 keV, the energy (wavelength) accuracy shall be <20% (TBR) of the energy (wavelength) resolution, with a goal of <10% (TBR).

From 10 – 40 keV, the energy (wavelength) accuracy shall be <TBD% of the energy resolution.

*Accurate energy (wavelength) scales (also known as registration) are required for line identifications, studies of radial velocity variations, and measurements of redshifts. These accuracies are driven by Science Objectives II and IV. For example, for stars and X-ray binaries, a 100 km/sec orbital velocity requires a relative error (during an observation or from observation to observation) of about 0.35 eV at 1 keV.*

*[At the 4/11/00 meeting, Kim Weaver noted that AGN velocity resolution requirements may be a science driver – it needs to be quantified a bit]*

### 3.4 Mission Effective Areas

The mission effective area requirements are defined on-axis at a set of nominal energies and are given in Table I below:

[This table needs to be revised by Jay/Bill/Rob to reflect Peak effective areas and average effective areas in a set of bandpasses. In the meanwhile, I have left it untouched. Also, it needs to be linked more closely with Table I]

**Table II**  
**Minimum Effective Areas**

Energy (keV)	Minimum Effective Area (cm <sup>2</sup> )
0.25 to 10	1,000
10 to 40	1,500
1.25	15,000
6.4	6,000
40	1,500

The mission effective area is defined to be the sum of the effective areas of all telescope systems (which meet the energy specific spectral resolution requirements) on all Constellation-X satellites when observing the same target. It is the geometric area of the optics for on-axis operation times all loss factors (excluding dead time corrections for detectors) including but not limited to the following (all possibly functions of energy):

1. Structural obscurations
2. X-Ray reflectivity of mirror coatings
3. Factors for division of photon throughput between e.g., Reflection Grating Array (RGA) reflected photons and non-reflected photons
4. Filters in the detectors
5. Quantum Efficiency of the detectors
6. Contamination of optical surfaces
7. Losses from mis-alignments and off-axis operation

*The minimum mission areas noted above are required to achieve Science Objectives I – IV. The nominal energies for the throughput requirements represent regions of the X-ray energy regime of*

particular interest, for example the iron K shell complex in the 6 keV regime and the broad iron L shell complex in the 0.7 to 1.2 keV regime. *The exact values of 1.25 keV and 6.4 keV were selected for a suitable calibration line from electron impact sources (Mg ka and Fe ka, respectively). Observing these emission complexes are required for understanding the physics of AGN, black hole accretion disks, SNR, and stellar coronae.*

*[Kim Weaver noted at the 4/11/00 meeting that recent CHANDRA AGN results emphasize the need for area at low energies (~0.5keV)]*

### 3.5 Photometric Accuracy

#### 3.5.1 Absolute Fluxes

Errors in the absolute flux determination (end-to-end throughput over the mission bandpass) of an on-axis source at any given wavelength shall be <10% (TBR) with a goal of 5%.

*Absolute photometric accuracy conditions are set to allow for comparisons of observations at different epochs for variable sources, especially low-intensity, long-term variability. The photometric accuracies are necessary to achieve Science Objectives I, II, III, and IV.*

#### 3.5.2 Relative Fluxes

Errors in the relative flux determinations of an on-axis source during a single observation shall be <5% (TBR) between 0.25 and 10 keV and <20% (TBR) between 10 and 40 keV. The goals shall be <2% (TBR) and <10% (TBR) respectively.

*Relative photometric accuracy conditions are set to allow for plasma diagnostics using line and/or continuum ratios within a given spectrum. The relative photometric accuracies are necessary to achieve Science Objectives I, II, III, and IV.*

*[The 5% may not be adequate for studies near edges or for weak equivalent width absorption features –]*

#### 3.5.3 Off-Axis Response

The additional absolute and relative errors of flux determination due to off-axis source locations shall be less than 1% (TBR).



*The addition of the off-axis error term is required to permit accurate studies of abundance variations as a function of location within extended sources such as SNRs and clusters of galaxies (i.e., typical SNR or clusters will fill the telescope field of view). The 1% is additive to the previous absolute and relative flux on-axis terms.*

### **3.6 Optics Angular Resolution**

The spatial resolution requirements for the optics are  $\leq 15$  arc-sec half-power diameter (HPD) from 0.25 keV to 10 keV and  $\leq 1$  arc-min above 10 keV. There is a goal to achieve a HPD of  $< 5$  arc-sec (TBR) from 0.25 keV to 10 keV and  $< 20$  arc-min (TBR) above 10 keV.

The PSFs shall be determined to TBR%.

*The spatial resolution specified is consistent with confusion-limited observations of the faintest source populations ( $2 \times 10^{-15}$  ergs  $\text{cm}^{-2} \text{ s}^{-1}$  in the ROSAT bandpass 0.25 to 2 keV; ??? in the CHANDRA bandpass 2 – 10 keV) to be studied. The stated spatial resolution is necessary to achieve Science Objective I, and allows for spatially resolved studies of extended objects in Science Objectives III and IV.*

### **3.7 Detector Field of View**

The non-vignetted on-axis field of view (diameter) of the imaging detectors shall be at least 2.5 arc-minutes below 10 keV and at least 8 arc-minutes above 10 keV. There is a goal to achieve on axis fields of view of 5 arc-min (TBR) and 12 arc-min (TBR), respectively.

*The minimum fields of view are set by the need to observe extended objects such as SNRs and clusters of galaxies, and to achieve Science Objectives III and IV.*

### **3.8 Detector Spatial Resolution**

Imaging detectors shall critically sample the PSF of their optics feeds.

### **3.9 Extended Source Capability**

The mission shall be capable of obtaining spectra with the stated spatial and spectral resolutions over the energy range of  $< 1$  (TBR) keV to 40 keV for sources that are larger in extent than the telescope beamwidth.

*The extended source capability is necessary to achieve Science Objective IV.*

### **3.10 Bright Source Capability**

#### **3.10.1 Point Source**

Point sources with count rates of up to 40,000 (TBR) counts per second between 0.25 and 10 keV for the mission effective area shall be observable without degradation of spectral resolution or timing precision. For count rates above 40,000 (TBR), timing precision shall not be degraded, but some spectral resolution degradation will be permitted.

Point sources with count rates of TBD counts per second between 10 and 40 keV for the mission effective area shall be observable without degradation of spectral resolution or timing precision.

*[These rates need to be looked at when Rich/Caroline provide a deadtime curve – j]*

#### **3.10.2 Extended Source**

Extended sources that fill the telescope field of view and produce count rates of up to 40,000 (TBR) counts per second between 0.25 and 10 keV for the mission effective area shall be observable without degradation of spectral resolution or timing precision.

Extended sources that fill the telescope field of view and produce count rates of up to TBD counts per second between 10 and 40 keV for the mission effective area shall be observable without degradation of spectral resolution or timing precision.

### **3.11 Radiation**

The mission and its instruments shall be designed to operate for the mission lifetime within the expected radiation environment. The science instruments shall be capable of calibrating the effects of the radiation on their performance and performance degradation.

*A new requirement to capture the FST and team concerns about the radiation environment at L2. Radiation may be direct or induced, particle or photon. It may also occur as part of the instrument structure.*

### **3.12 Timing Requirements**

#### **3.12.1 Timing Accuracy**

Over the mission bandpass individual photon arrival times shall be measured to an accuracy of +/-100 microseconds (TBR) relative to UTC. The goal is +/- 50 (TBR) microseconds.

*The timing accuracy is driven by the need to compare times of events as measured at different observatories, both space- and ground-based, and to allow for accurate measurements of time variable phenomena.*

#### **3.12.2 Timing Resolution**

For each individual satellite the time resolution shall be +/-10 microseconds with a goal of +/-1 microsecond. This requirement does not apply to the mission as a whole.

*The time resolution is driven by the need to study highly variable phenomena in black hole and neutron star accretion disks, and pulsar spin rate changes, and burst sources.*

### **3.13 Celestial Coordinate Accuracy**

The mission shall provide a celestial location accuracy (post-facto reconstruction) of 5 arc-seconds (3 sigma). There is a goal to achieve a celestial location accuracy of 1.5 arc-seconds (3 sigma) (TBR).

*A precise celestial location is required to enable comparison of source positions (and hence source identification) between Constellation-X and other ground- and space-based observatories. This accuracy is necessary to achieve Science Objective I.*

### **3.14 Observation Duration**

Individual, uninterrupted, observations utilizing the full mission collecting area shall be between 0.5 (TBR) hours and 48 (TBR) hours in duration.

*Observations that require more than 48 contiguous hours can be accommodated by multiple individual observations. Such observations may be for faint objects, or for objects with variability on timescales of several days.*

### **3.15 Re-pointing**

The mission must be capable of a slew and settle time less than 1 hour (TBR).

### **3.16 Solar-System Objects**

The mission shall be capable of observing solar system objects.

### **3.17 Sky Coverage**

The mission orbit and attitude constraints must be such that 90% of the sky is accessible at least twice per year, with viewing windows not shorter than 2 weeks in duration; and 100% of the sky is available at least once a year with a minimum viewing window of one week. The goal is for nearly complete sky coverage (allowing for Sun, Earth, and Moon avoidance zones).

### **3.18 Real Time Observing**

There is no requirement for real-time observing during normal science operations

### **3.19 Targets of Opportunity**

Targets of Opportunity (TOOs) shall be observable within 24 hours notice to the Project Scientist and with a goal of 12 hours. TOOs shall be limited to no more than 2 (TBR) per month.

*The limitation on the number of TOOs per month is per the FST (meeting date June 00) to avoid large impacts on the mission support staff, and on the mission observing plan.*

### **3.20 Data Rate**

The average data rate that shall be accommodated by the mission is 192 kbps (TBR).

The peak data rate that shall be accommodated by the mission is 5,460kbps (TBR).

*The average data rate is determined by the nature of the instruments in the reference mission description. The average data rate can drive the downlink requirement. Peak data rates (and duration of such observations) will determine the required on-board storage capacity. The above rates do not properly reflect the timing requirement, nor the existence of the zeroth order CCD.*

*[It may be better to specify this as incoming photon rate, and then flow it down to the instruments. I'd appreciate feedback on this point – JB]*

### **3.21 Data Latency**

Data shall be available to the investigator within 2 weeks of the completion of an observation. The goal shall be 72 hours. Bright source observations (i.e, where the data rate significantly exceeds the average rate) shall be made available to the investigator within 2 weeks (TBR) of the completion of the data downlink. Source observations requiring precision timing shall be made available within 45 (TBR) days.

### **3.22 Viewing Efficiency**

An overall viewing efficiency of 90% is required.

*[There was some sentiment at the 4/11/00 meeting that this should exclude slew time. I'd like to see a rationale that we need to do this before I make the change.]*

### **3.23 Mission Lifetime**

#### **3.24**

Constellation-X satellites shall be designed for a minimum normal mission operations lifetime of four years. Consumables shall be sized for a minimum of 6 years of normal missions operations, and with a goal of 10 years.

*The number of sources that need to be observed extensively with Constellation-X is in the hundreds, and it would not be possible to cover statistically adequate numbers of the variety of classes of sources in less time. Many galactic sources have important timescales of months to years, either binary periods, precession periods of accretion disks, significant precession of eccentric orbits, or decay of short period orbits. Fluctuations in pulse periods of accreting pulsars have timescales of months, and galactic X-ray novae have decay times of up to a year.*

### **3.25 Redundancy**

The Constellation-X mission shall be configured such that no single failure will result in the loss of more than 25% (TBR) of the mission science, exclusive of launch vehicle failure.

### **3.26 Reliability**

The probability of success that 75% of the mission meets the mission design life requirement shall be 75%, including the launch vehicle..

#### 4. ACRONYMS

AGN	Active Galactic Nuclei
CCD	Charge-Coupled Device
CPS	Counts per second
HPD	Half-power diameter
ICM	Intra-Cluster Medium
IGM	Intergalactic Medium
ISM	Interstellar Medium
keV	kilo-electron volt
PSF	Point Spread Function
RGA	Reflection Grating Array
SI	Science Instrument
SNR	SuperNova Remnant
UT	Universal Time
TBD	To Be Determined
TBR	To Be Revised